EFFECT OF ADAPTATION TO HIGH MOUNTAIN CONDITIONS ON HUMAN RESISTANCE TO ACUTE HYPOXIA AND HIGH TEMPERATURE

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Acclimatization to high mountain conditions, an essential element of which is adaptation to existence under conditions of a lowered partial pressure of oxygen in the inspired air, is regarded by many investigators as an effective method of increasing the adaptation reserves of the body [1, 3, 4, 6].

Investigations on animals have shown that after a long stay at a lowered barometric pressure animals are more resistant to any action of many unfavorable external environmental factors: an acute deficiency of oxygen in the inspired air, a high temperature, increased gravitational force, ionizing radiation, etc.

Most clinically healthy persons, after a relatively long stay in the mountains at an altitude of the order of 2000-7000 m, are more resistant for a certain length of time to the action of acute hypoxia than healthy persons who are not altitude trained [2, 3, 5]. /281

It has also been found that daily training for 1 month in a pressure chamber at an "altitude" of 6000 m not only increases the altitude resistance of clinically healthy persons, but also increases their resistance to the action of high and low temperature [6].

The object of this investigation was to study the effect of adaptation to high mountain conditions on the resistance of healthy persons to the action of acute hypoxic hypoxia and to the action of a high external environmental temperature.

We were interested in whether it is possible and desirable to use adaptation to high mountain conditions as a method of increasing man's resistance to various experimental factors of flight.

METHOD

The investigation was carried out with different groups of clinically healthy persons: 11 highly skilled athletes, 10 physically well-developed young men not previously living in the mountains, and the 5 research workers taking part in the present investigation.

In 1964, five healthy men were adapted to high mountain conditions in stages: 12 days at an altitude of 2000 m (Terskol); 12 days at 3800 and 4200 m ("Ledovaya Baza" and "Refuge II") and 5 days at an altitude of 2000 m again. In 1965 the length of stay at an altitude of 3800-4200 m of the same group of subjects was lengthened to 20 days.

The mountaineers stayed for 6 days at an altitude of 2000 m (Tereskol), and then completed their ascent.

The research worker group spent most of their time for 25-28 days at an altitude of 2000 m (Terskol), but periodically in connection with their work they climbed to "Ledovaya Baza" and for a short time to "Refuge II." Including overnight stays, each worker spent from 4 to 6 days at "Ledovaya Baza."

High-altitude experiments. Before and after their stay in the mountains the members of the expedition had their resistance to high altitudes determined. Under pressure chamber conditions, the subjects were raised in stages, without oxygen, to a high altitude until they began to show clear signs of profound hypoxia, such as gross disturbances of writing, inability to solve elementary arithmetical problems, clonic spasms of the writing hand (writer's cramp), and disturbances of consciousness of different degrees.

In the first experiments with five subjects the altitude up to which the pressure chamber was "raised" before and after their stay in the mountains did not exceed 7000 m, and only the length of their stay at this altitude was considered. /282
In all the other experiments the pattern of the ascent was as follows. Up to an altitude of 5000 m at a speed of 25 m/sec, with a pause of 15-20 sec or thereabouts every kilometer, starting from an altitude of 5000 m a pause of 5 min at each successive altitude.

Before, during and after completion of the ascent recordings were made of the following in all subjects: the electroencephalogram (EEG) in the fronto-occipital lead, the electrocardiogram (ECG) in three standard leads, the respiratory movements of the chest wall, and (periodically) the arterial pressure and the oxygen saturation of the arterial blood. Throughout the experiment continuous observations were kept on the subject's behavior and general condition.

To assess his working capacity and intellectual activity, during his stay at a high altitude the subject was given arithmetical problems to solve (multiplication of double-figure numbers).

HEAT EXPERIMENTS

Altogether 24 high-temperature experiments were carried out in a combined heat- and pressure-chamber at normal barometric pressure and at an environmental temperature of +70° (temperature of chamber walls between +90 and +92°), the relative humidity being 40%.

The subjects wore shorts and sat in the armchair provided in the chamber. No ventilation was present in the chamber.

In the course of the experiments the subjects were kept under continuous medical observation and two-way radio communication was maintained. Every 10 min recordings were made of the ECG in lead II, the respiratory movements of the chest wall, and the body temperature by means of an alcohol thermometer under the tongue. By weighing the subjects on medical scales before and at the end of the experiment the loss of moisture could be determined.

The subject's general condition was assessed from how they felt subjectively and from their temperature sensation.

RESULTS

A distinct increase in resistance to high altitudes was found in 5 subjects taking part in the first expedition after their stay in the mountains.

Four subjects spent a period of 20-30 min without oxygen at an "altitude" of 7000 m after their return from the mountains, and during this time their general condition remained perfectly satisfactory and their ability to work continued at a high level.

Interesting results were obtained by investigation of subject P-is, whose ECG taken before his trip to the mountains, after physical exertion (20 knee-bendings in 40 sec), during rotation on a centrifuge, and also during ascent in the pressure chamber revealed ventricular extrasystoles, increasing in intensity with an increase in load. Their appearance made it necessary to terminate the investigation at an altitude of 5000 m after only 3 min to keep the subject's general condition satisfactory. After a stay in the mountains, including ascent of the eastern summit of El'brus, no cardiac arrhythmias were found in the examination of this subject in the pressure chamber in the course of a 30-minute stay at 3000 m, and he tolerated the high-altitude experiment well. The remaining subjects remained in the pressure chamber for between 1 and 9 min only, when taken to an altitude of 7000 m before their trip to the mountains.

In subsequent experiments we made a few modifications to the technique of determining resistance to high altitudes so that the results of experiments with different groups of subjects could be compared.

As our earlier investigation (V.B. Malkin, N.M. Asyamolova and A.K. Kochetov) showed, mountaineers possess high resistance to altitude and, as a rule, they feel well at an altitude of 7000 m for a long time; for that reason, when investigating this group of subjects, it was essential to take them up to higher altitudes in order to determine their altitude resistance.

Data for the altitude resistance of the three different groups of subjects before and after a stay in the high mountains are given in the table.

In the case of young men going to the mountains for the first time, feeling fit while they were there, and successfully climbing to the eastern summit of El'brus, their stay in the mountains led to an appreciable (in 3 of 5) increase in altitude resistance. The resistance of one subject, who suffered from mountain sickness, fell slightly and that of another, whose initial background resistance was high, increased relatively slightly.

The changes in altitude resistance of the mountaineers were slight: in 4 the resistance was practically unchanged (a change of less than 30 sec), in one it fell and in 6 it increased. However, in 2 of these 6 subjects the increase was due to the fact that their background resistance was lower than in the previous experiments with the same subjects.

A significant increase in resistance in this group was in fact obtained with only 3 subjects, two of whom went to the mountains after a relatively long interval. This was evidently the cause of the lower background resistance of these subjects.

We attempted to find a relationship between the adaptation regime in the mountains and the altitude resistance of the mountaineers. No increase in altitude resistance was found in two mountaineers (Ts-n and K-ov), who had the greatest load and stayed at altitudes of the order of 4000-4800 m for longer than the others: in one it fell and in the other it remained substantially unchanged. /284

TABLE. Changes in Altitude Resistance Before and After a Stay in the Mountains

Surname	Before stay in mountains		After mountains on 4th-6th day		After mountains, on 28th-32nd day		Changes in resistance
	altitude, km	time, sec	altitude, km	time, sec	altitude, km	time, sec	
Subjects							
A-ev	9	120	8	300	8	300	Lowered
V-ko	9	190	9	60	8	300	Raised
K-as	7	300	8	2700	8	220	The same
Sh-k	8	90	9	70	—	—	The same
K-us	9	50	9	140	9	100	The same
Mountaineers							
Ts-n	8	240	8	240			Unchanged
K-ov	9	110	8	300			Lowered
K-in	9	70	9	200			Raised
K-ev	9	110	9	130			Unchanged
T-m	8	120	9	165			Raised
S-t	9	160	9	140			Unchanged
B-ov	9	40	9	120			Raised
N-ov	8	90	8	250			The same
G-r	8	300	9	100			The same
B-d	9	40	9	130			The same
M-n	9	70	9	60			Unchanged
Research workers							
U-a	8	80	8	270			Raised
R-a	7	70	8	150			The same
L-a	7	90	8	120			The same
M-ko	6	300	7	110			The same
M-ns	5	270	5	300			Unchanged

I consider that it would be premature to attribute these results to excessive physical exertion, for some increase in altitude resistance was observed among

the mountaineers, including among those who took part in an expedition to the Tyan'-Shan' (Khantengri district), making a difficult climb with a heavy load and staying for a relatively long time at altitudes of 6000-7000 m.

Three of the 5 research workers showed a distinct increase in altitude resistance after a stay in the mountains, one showed a very slight increase, and the remaining one, with low resistance, showed no change. This last case (M-is) merits special attention, because when this subject was taken up in the pressure chamber to an altitude of 5000 m before making his trip to the mountains, he unexpectedly developed bradycardia, lost consciousness, and had a fit. While in /285
the mountains, M-is worked at altitudes of 3800-4200 m and felt perfectly fit, although after staying 5 min at an altitude of 5000 m he again developed severe bradycardia and a state of precollapse.

We were concerned above all to discover the causes of the marked increase in altitude resistance arising in some cases after adaptation in the mountains.

Analysis of the results of recording the physiological parameters showed that the respiration of these subjects was intensified to the greatest degree at a high altitude, as a result of which the oxygen saturation of their arterial blood was considerably higher during elevation to a high altitude in the pressure chamber after a stay in the mountains than during the control elevation (Fig. 1).

This factor also probably determined the changes in higher nervous activity of the subjects and in the bioelectrical activity of their brain. After returning from the mountains they were able to remain capable of working, with a relatively unchanged EEG, for longer then before their stay in the mountains.

Very strikingly, the oxygen saturation of the arterial blood of the subjects showing an increase in altitude resistance either was the same as in the control investigation at the moment of completion of the altitude test or, in a few cases, it was actually a little higher. These findings demonstrate that a stay in the mountains (adaptation to chronic hypoxia) does not enable the body to maintain a sufficiently high level of ability to work under the conditions of a reduced oxygen supply, but is accompanied by a more efficient and more precisely adjusted activity of its functional systems responsible for the transport of oxygen to tissue structures most sensitive to hypoxia.

The fact that different groups of subjects showed different changes in altitude resistance is probably connected to some extent also with differences in the course of the acclimatization process itself, clearest evidence of which is provided by the decrease in altitude resistance of subject A-ev, who suffered from mountain sickness, and also by the results of the hematologic tests (I.A. Roshchina). Blood tests performed on the group of young men visiting the mountains for the first time showed a definite increase in hemoglobin concentration and erythrocyte count, corresponding to the altitude to which they climbed; the same response, but less marked, was also found among the research workers, whereas among the mountaineers it was hardly noticeable.

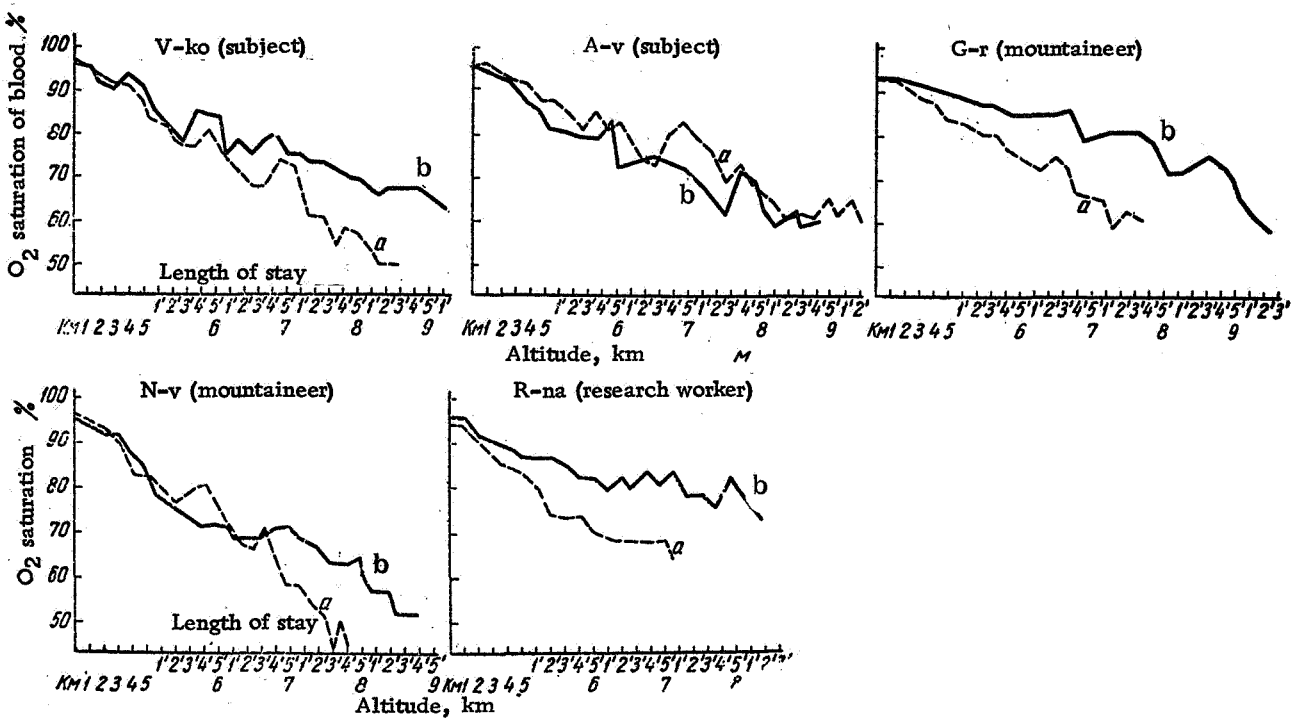

Figure 1. Changes in Oxygen Saturation of Arterial Blood During Elevation in a Pressure Chamber Before (a) and After (b) a Stay in the Mountains.

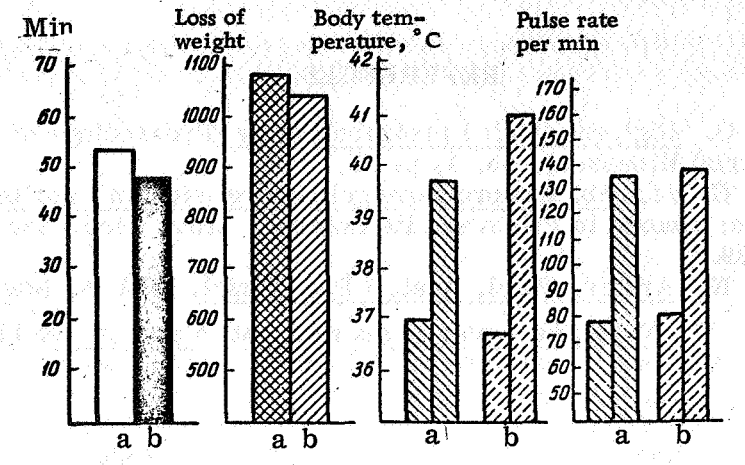

Figure 2. Length of Stay in Hot Chamber at a Temperature of +7°, Together With Change in Weight, Body Temperature and Pulse Rate Before (a) and After (b) a Stay in the Mountains (Mean Data for 11 Persons).

A fact of definite practical interest is that the increase in altitude resistance, like the resistance to the action of radial acceleration, persists for a month or even longer after high-mountain adaptation.

The results of our high-temperature experiments were somewhat unexpected. /287 We had considered that a stay in the mountains would lead to an increase in the subjects' resistance to a high temperature. Moreover, in experiments performed jointly with F. V. Babchinskiy on animals, a significant increase in the survival rats of mice adapted in the mountains was observed at a temperature of +60°.

The results given in Fig. 2 show that the resistance of most of the subjects to a high temperature 10-14 days after their return from the mountains showed a slight decrease. It is important to note that the rise of body temperature, the main criterion of the reaction of the body to overheating, took place appreciably faster in nearly all the subjects after their stay in the mountains than in the control experiments.

After their return from the mountains the subjects' general condition toward the end of their stay in the hot chamber was appreciably worse than in the control experiments. This explained why two subjects after adaptation in the mountains were in a state of precollapse when the experiment was stopped, whereas all the control experiments were stopped at the subjects' request, because they had begun to feel unpleasant effects from the heat. The impression was thus created that, although after adaptation to high mountain conditions the subjects were able to endure a higher increase of body temperature, their resistance was nevertheless slightly lowered.

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